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TIME-TEMPERATURE RELATIONS IN DIFFERENT TYPES OF PEACH-ROT INFECTION

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BY

CHARLES BROOKS AND J. S. COOLEY
(Contribution from Bureau of Plant Industry)

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TIME-TEMPERATURE RELATIONS IN DIFFERENT TYPES OF PEACH-ROT INFECTION[1]

By CHARLES BROOKS, *Principal Pathologist*, and J. S. COOLEY, *Senior Pathologist*, *Office of Fruit Diseases, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

Car-lot shipments of peaches frequently show considerable spoilage upon arrival at their destination, and this spoilage is usually in the form of Monilia and Rhizopus rots. The behavior of these rots at various constant temperatures was described in an earlier publication.[2] Data were also reported on the effect of delays in cooling. The present paper reports further studies on the temperature responses of Monilia and Rhizopus, includes experimental data on their behavior in a gradually falling temperature such as prevails in a refrigerator car, shows the contrasts in the incubation period at different temperatures and with different types of inoculation, and attempts to equate the different growth and incubation values. It also gives shipping results from sprayed and unsprayed fruit.

EQUATION OF TEMPERATURE VALUES

METHODS

Experiments were made at various constant temperatures with different types of inoculation, and the various responses were reduced to a basis of comparison. Three different methods of inoculation were used: (1) Forcing the spores into the peaches with a needle, (2) puncturing the peaches and then dusting them with spores, and (3) dusting unpunctured peaches.

The needle inoculations were made by pushing spores to a depth of 3 to 6 mm. into the flesh of the peach with a coarse needle. The dusting inoculations were made by placing the fruit in a large paper bag along with rotten but firm peaches carrying a good covering of spores, and rolling the two lots gently back and forth from one end of the bag to the other. In the Rhizopus dusting experiments, fruiting Petri-plate cultures were sometimes substituted for the rotten peaches as inoculation material.

As mentioned above, a part of the dusted peaches had been previously punctured. Except where otherwise stated, 10 punctures were made on each peach with No. 18 wire (paper-clip wire). As a matter of convenience wires were mounted in a large cork at distances of 12 to 15 mm. apart, and this group of wires was forced first into one side of the peach and then into the other.

[1] Received for publication Aug. 17, 1928; issued December, 1928.

[2] BROOKS, C., and COOLEY, J. S. TEMPERATURE RELATIONS OF STONE FRUIT FUNGI. Jour. Agr. Research 22: 451-465, illus. 1921.

The peaches used in the experiments were selected with great care so that those of the different lots would be alike in maturity, in size and color, and in freedom from evident bruises and blemishes. Eight to ten peaches were used under each condition tested, and most of the experiments were repeated fifteen to twenty times. Before the inoculations were made [3] the peaches were cooled to approximately the temperature at which they were later to be placed.

The fungi used in the inoculations were obtained from active peach rots. They were apparently *Sclerotinia fructicola* (Wint.) Rehm and *Rhizopus nigricans* Ehr. and are referred to in the present paper as Monilia and Rhizopus.

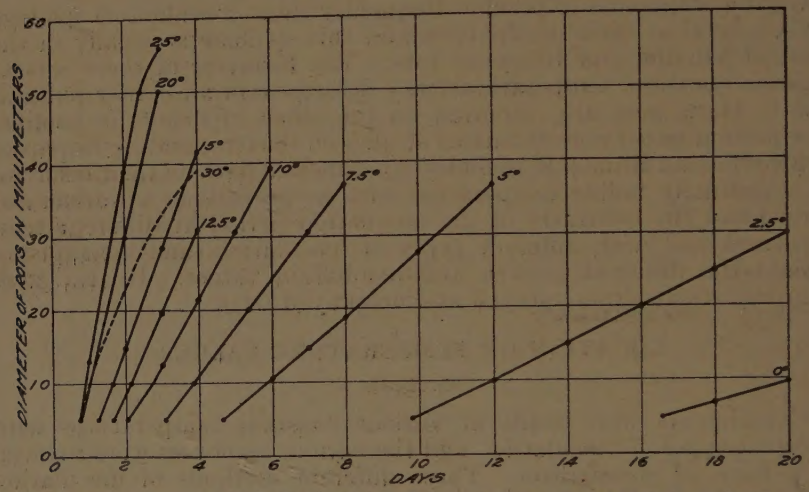

FIG. 1.—Growth curves of Monilia needle-inoculation rots on peaches at various constant temperatures; the average of results from 20 series of experiments, 1 with Carman, 4 with Hiley, 8 with Belle, and 7 with Elberta. There was little contrast between the different varieties, but the results from the individual experiments sometimes varied as much as 2 per cent from the average in the rate of growth and 10 per cent from the average in the period of incubation. In the growth at 30° C. and in the incubation period at 0° and 2.5°, the variation was sometimes even greater than this. The results reported are based on peaches showing 10 to 16 pounds pressure with a standard pressure tester, but similar results were obtained at the higher temperatures and only slightly accelerated development at the lower temperatures with peaches showing 5 to 10 pounds pressure

MONILIA NEEDLE INOCULATIONS

The results with the Monilia needle inoculations at constant temperatures are shown in Figure 1. It will be seen that considerable time was required for the rots to become established, especially at the lower temperatures, but that after this incubation period they increased in diameter in a fairly uniform manner, requiring approximately the same number of hours to enlarge from a 10 mm. to a 20 mm. diameter as to enlarge from 20 mm. to 30 mm. Usually the same rate of growth continued upward to a diameter of 40 mm. or more and downward to a diameter of 5 mm. At 30° C., however, there was a continual slowing up of the growth rate after the rot had attained a diameter of 15 mm. At some of the lower temperatures the rate of increase in diameter was not always as rapid between 5 mm.

[3] In an earlier report the inoculations were made on warm peaches. BROOKS, C., and COOLEY, J. S. Op. cit.

and 10 mm. as in the later stages of growth, but this difference has largely disappeared in the averages, as shown in Figure 1.

The rate of increase in diameter at the different temperatures is graphically shown in the smoothed curve (*a*) of Figure 2. This curve is based on the growth values shown in Figure 1 and has been found to hold both for rots started at the given temperatures and for those started under room or field conditions and then transferred to these temperatures.

It is obvious that with a uniform increase in diameter at a particular temperature, as described above, there was a progressive increase in the volume of work accomplished per hour as the rot enlarged, the actual quantity of tissue broken down in one hour during the 20 to 30 mm. stage being much greater than that broken down in one hour during the 10 to 20 mm. stage. The rots at the higher temperatures, therefore, are soon in a later and a more enlarged period of growth than those at the lower temperatures, making any temperature comparison invalid if based on volume of rot or weight of rotten tissue or on actual work accomplished in a specified hour, at a considerable period after inoculation. Comparisons based on the rate of increase in diameter, however, are not subject to this criticism, since, as pointed out above, the rate of increase is usually practically the same over the larger part of the period of growth.

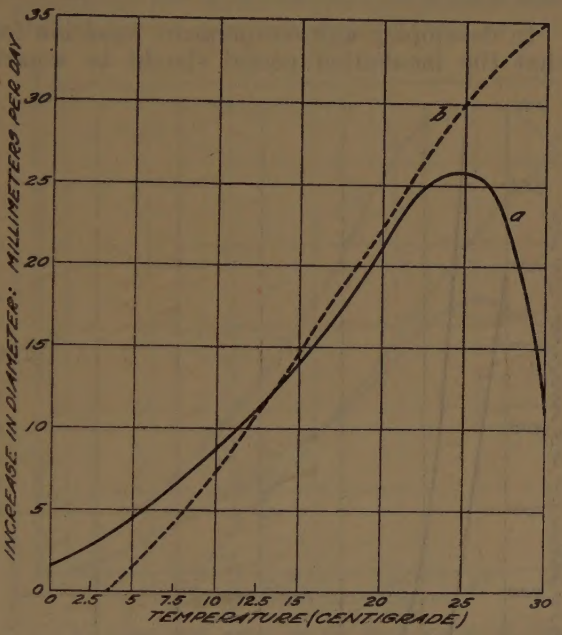

FIG. 2.—Temperature curves based on the hourly increase in the diameter of the rots as shown in Figures 1 and 9. Curve *a*, Monilia; *b*, Rhizopus

Probably the best basis for any temperature comparison is that of the number of hours required to complete a particular stage of development, especially in any study involving the incubation period. It is interesting to note that at temperatures from 15° to 25° C. approximately the same number of hours were required for the Monilia rots to get started and grow to a diameter of 10 mm. as for them to enlarge from a diameter of 10 mm. to one of 30 mm.; whereas at the lower temperatures more time was required for the first of these periods of development than for the second and at 30° much more time for the second than for the first. (See Table 1 and fig. 1.)

TABLE 1.—*Rate of development of Monilia rots at different stages and temperatures, based on the growth curves of Figure 1*

Growth period	Approximate number of hours required at stated temperatures (° C.)									
	30°	25°	20°	15°	12.5°	10°	7.5°	5°	2.5°	0°
From time of inoculation up to a diameter of 10 mm	23	21	25	39	51	65	91	142	288	480
From a diameter of 10 mm. to one of 30 mm	39	19	24	36	44	54	73	110	195	------

In developing any temperature equation for Monilia it is evident that the incubation period should be separated from the growth period and that the line of separation should be made at the earliest possible stage. The curves of Figure 1 would seem to justify making this dividing line at the point where the rots have attained a diameter of 5 mm. (0.2 inch). Taking this as the dividing line, it is seen that at 30° C. the incubation period was about 19 hours; at 25°, 17.5 hours; at 20°, 19.5 hours; at 15°, 31 hours; at 12.5°, 40 hours; at 10°, 50 hours; at 7.5°, 75 hours; at 5°, 112 hours; at 2.5°, 235 hours; and at 0°, 400 hours. These values are shown in curve *a* of Figure 3.

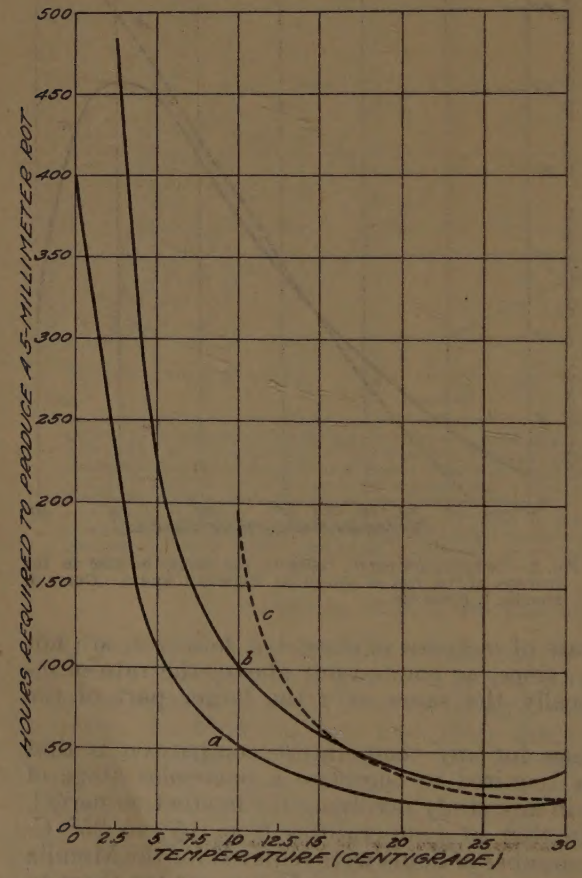

FIG. 3.—Temperature curves based on the average number of hours required to produce a 5-mm. rot as shown in Figures 1, 5, and 7. Curve *a*, Monilia needle inoculations; *b*, Monilia dusting inoculations on punctured peaches; *c*, Rhizopus needle inoculations. Curve *b* can also be regarded as showing the approximate number of hours required to bring the percentage of infection up to 20

Since these records in hours are a measure of the time required to do a certain volume of work, the reciprocals of these hour values give the relative work accomplished at the different temperatures in a given time. These reciprocal values are the basis for curve *a* of Figure 4. It will be seen from this curve that at 5° C. about four times as much work was accomplished as at 0°, about three times

as much at 7.5° as at 2.5°, about 120 per cent more at 10° than at 5°, about 90 per cent more at 12.5° than at 7.5°, about 60 per cent more at 15° than at 10°, about 60 per cent more at 20° than at 15°, about 12 per cent more at 25° than at 20°, and about 10 per cent less at 30° than at 25°.

The above temperature contrasts for the incubation period should be compared with the temperature contrasts for the growth period as shown in curve *a*, Figure 2. A study of this curve shows that the growth at 5° C. was about three times as fast as at 0°, the growth at 7.5° about two and six-tenths times that at 2.5°, the growth at 10° about twice that at 5°, the growth at 12.5° about 75 per cent greater than that at 7.5°, the growth at 15° about 55 per cent greater than at 10°, the growth at 20° about 50 per cent greater than at 15°, the growth at 25° about 25 per cent greater than at 20°, and the growth at 30° less than half that at 25°. It will be seen that at the lower temperatures a 5° change had greater significance in the incubation stage of the fungus than in the growth stage and that with both incubation and growth the effect of a 5° change was far greater at the lower temperatures than at the higher ones.

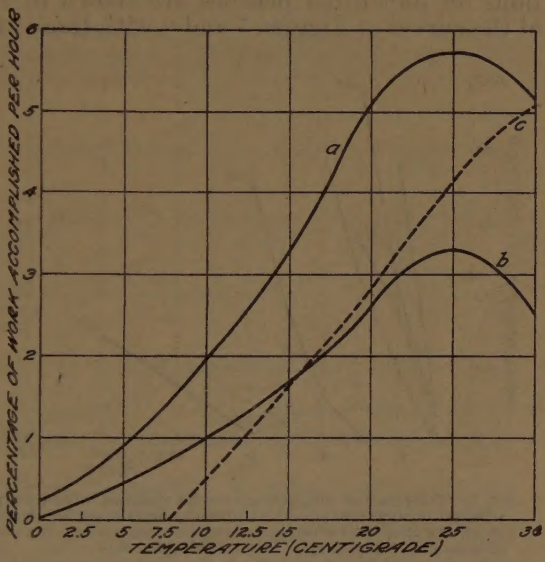

FIG. 4.—Temperature curves for the incubation period, showing the percentage of work accomplished per hour based on the reciprocals of the values shown in Figure 3. Curve *a*, Monilia needle inoculations; *b*, Monilia dusting inoculations; *c*, Rhizopus needle inoculations

MONILIA DUSTING INOCULATIONS

With needle inoculations all of the rots at a particular temperature usually started at practically the same time, but with the peaches that were punctured and dusted some of the rots were often twice as long as others in starting.

The time at which the rots appeared on the punctured and dusted peaches at the various temperatures is shown in Figure 5. At 25° C. about 10 per cent of the punctures had rots by the end of the first day and 76 per cent by the end of the second day; at 20°, 8 per cent the first day, 42 per cent the second day, and 96 per cent the third day; at 30°, 36 per cent the second day and 54 per cent the third day; at 15°, 19 per cent the second day and 78 per cent the fourth day; at 10°, 12 per cent the fourth day and 72 per cent the sixth day; at 5°, about 3 per cent the sixth day, 16 per cent the eighth day, and 29 per cent the tenth day; and at 2.5°, about 6 per cent the thirteenth day and 30 per cent the nineteenth day. It will be seen that the lower

the temperature the greater was the period of time over which infections occurred and that there was a fairly close ratio between the spread of the infection period and the time required to produce the first rot. The final percentage of infection (fig. 5) was much higher at temperatures near the optimum for the fungus than at those distinctly below or above the optimum. This was largely a direct temperature response, but one other factor should be mentioned. The discontinuance of infection records was usually brought about by the absorption of the uninfected punctures in the growth of the rots already started. At the lower temperatures growth was not inhibited to the same relative degree as infection, and therefore the records may have been closed relatively earlier at these temperatures.

The growth curves for the rots resulting from the dusting inoculations on punctured peaches are shown in Figure 6. A comparison of the curves of Figures 5 and 6 with those of Figure 1 shows that the

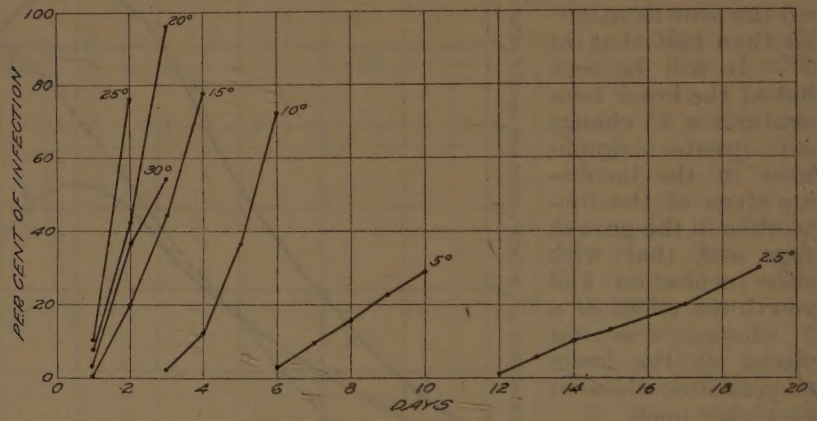

FIG. 5.—Temperature infection curves for peaches dusted with Monilia spores. Each peach had received 10 punctures previous to dusting, and the curves show the percentages of infection at these punctures after the various periods of time indicated on the base line. The results are the average of 16 series of experiments. (See legend of fig. 6)

rots from the dusting inoculations were greatly delayed as compared with those from the needle inoculations. This is brought out more strikingly in the curves of Figure 3, showing the number of hours required for the diameters of the rots to reach an average of 5 mm. and those of Figure 4, showing the relative volume of work accomplished per hour during the incubation period. It will be seen that it took approximately twice as long for a rot to get started when the spores were dusted over a puncture as when they were forced into the flesh with a needle. At 25° C. it did not take quite twice as long, and at 5° and 2.5° it took more than twice as long.

These incubation values for the dusted peaches are based on the number of hours required for the average diameter to reach 5 mm. and are not identical with values obtained by taking an average of the number of hours required to produce a 5-mm. rot. With the latter method of computation all of the rots that eventually appeared at the punctures would be considered in the earlier as well as the later

valuations, and the number of hours required for the incubation period as shown in Figure 3 would be thus increased approximately 30 per cent. This computation would make the incubation period for the punctured and dusted peaches more than two and a half times as long as that for the needle inoculations, instead of twice as long, as reported above.

Two reasons can be assigned for the earlier development of the rots from needle inoculations than from puncturing and dusting: (1) The needle inoculations carried more spores into the flesh of the peach than would be lodged around a single puncture by the dusting method, and (2) a spore located in the moist, broken tissue of the flesh has much more favorable conditions for quick germination and the rapid production of a rot than one located on the surface of the peach at or near a puncture.

A comparison of the curves of Figure 6 with those of Figure 1 would indicate that the growth rate of the rots resulting from dust

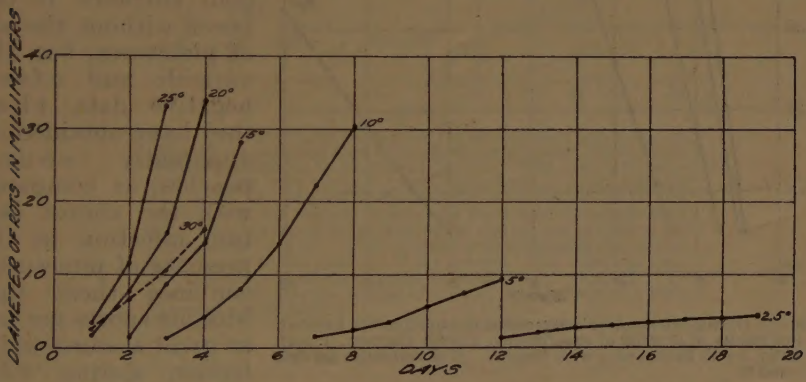

FIG. 6.—Growth curves of rots produced at various constant temperatures by dusting punctured peaches with Monilia spores. The results are the average of 16 series of experiments; 4 with Hiley, 7 with Belle, and 5 with Elberta. There was little contrast between the different varieties, but the results of the individual experiments sometimes varied as much as 50 per cent from the average, and at 5° C. and below the variation was greater than this. These variations, however, were largely between one series of experiments and another with the temperature ratios of the different series remaining fairly uniform. The results as reported are based on peaches showing 10 to 16 pounds pressure, but rots have developed with only slightly more freedom and rapidity on peaches showing 5 to 10 pounds pressure

inoculations was slower than that of the rots from needle inoculations; but such was not the case. The rots when once established grew at practically the same rate, regardless of the method of inoculation; and the relatively slow growth rate indicated for the early stages of the dust inoculations is due to the fact that the continual appearance of new rots prevented the increase in the average diameter from being a true record of the actual rate of growth.

As previously mentioned, apparently sound peaches as well as punctured ones were included in the dusting experiments. A record was also kept of the rots developing on the punctured peaches at points other than the punctures and of those developing on check peaches, which were neither punctured nor dusted. The results of these experiments have been extremely variable and very difficult to interpret. In most cases practically no rots developed from dusting unpunctured peaches with Monilia spores, but in some instances there were one-fourth to one-half as many rots on the unpunctured

peaches as on the punctured ones. These rots were usually considerably delayed as compared with those occurring at the puctures.

It is possible that the extreme variation in these dusting experiments was due in part to a difference in the condition of the rotten peaches used as inoculation material, as it was observed that any juice or small particles of flesh from the rotten peaches might be an aid to infection when lodged upon the sound ones. Great care was taken, however, to avoid this by selecting inoculating material that was in a firm condition. It is also possible that rolling the peaches back and forth in the bags sometimes resulted in small punctures or abrasions that were of material assistance in the starting of the rots. The writers do not question the ability of germinating Monilia spores to gain entrance to the peach without the aid of punctures, but the variable and often negative data that they have obtained on apparently sound peaches, as compared with the almost certain infection in the presence of punctures, convince them that Monilia spores are not as great a source of infection during the usual periods in transit as is commonly supposed, except when aided by bruises, punctures, or similar favoring conditions.

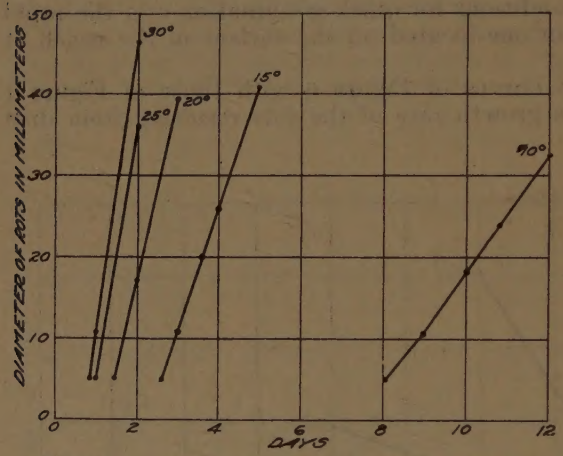

FIG. 7.—Growth curves of Rhizopus needle-inoculation rots; based on the results of 12 series of experiments, 2 with Carman, 1 with Hiley, 5 with Belle, and 3 with Elberta. (For variations see figs. 8 and 9)

RHIZOPUS INOCULATIONS

The results with Rhizopus were less uniform than those with Monilia. Even at the higher temperatures, the maturity of the fruit, the condition of the fungus, and other factors seemed to have an important modifying influence, and at 15° C. and below the results were quite variable, especially as to the period of incubation and percentage of infection.

The data for the Rhizopus needle inoculations on fruit that had been previously cooled to approximately the temperature at which it was to be stored [4] are shown in Figures 7 and 8, and the rate of growth for rots that had started before being placed at the various temperatures is shown in Figure 9. The rate of increase in diameter at the various temperatures is shown in the smoothed curve *b* of Figure 2 and the incubation period in curve *c* of Figure 4.

It will be seen that the early development of Rhizopus was much slower than that of Monilia, especially at the lower temperatures,

[4] In an earlier report the inoculations were made on warm peaches. BROOKS, C., and COLEY, J. S. Op. cit.

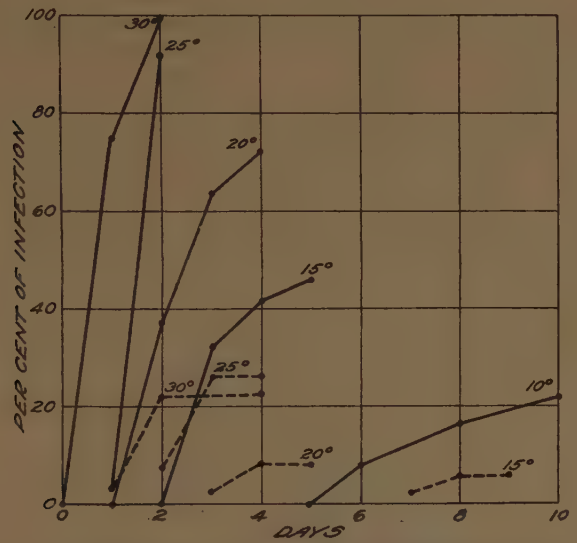

FIG. 8.—Temperature curves showing the percentage of infection with Rhizopus inoculations; solid lines, needle inoculations; broken lines, dusting inoculations on punctured peaches. With the needle inoculations there were variations from the average as great as 25 per cent at 30°, 25°, and 20° C. and as great as 100 per cent at 15° and 10°; and with the dusting inoculations there were variations from the average as great as 50 per cent at 30° and 25° and as great as 100 per cent at 20° and 15°. The variations were apparently due in part to differences in the maturity of the peaches. The needle-inoculation results are based on 12 series of experiments. (Fig. 7.) The dusting results are the average of 5 series of experiments, 1 with Hiley and 4 with Belle

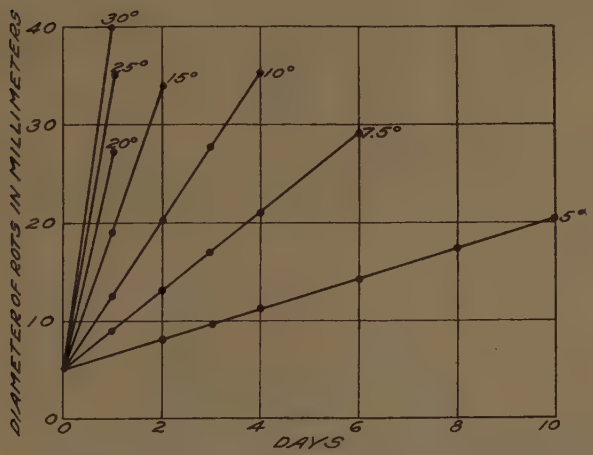

FIG. 9.—Rate of growth at different temperatures for Rhizopus rots that were already started, based on the results of 16 series of experiments at the higher temperatures and 5 series at 7.5° and 5° C. Some of the individual experiments varied from the average as much as 15 per cent. A part of this variation was apparently due to differences in the maturity of the fruit

but that when once established the rots enlarged more rapidly than those of Monilia at all of the higher temperatures, especially at 25° C. and above. Rhizopus was much more responsive to temperature changes than Monilia. It made a better development at 30° than at any other temperature tested, whereas this was above the optimum for Monilia. It was unable to start rots on peaches previously cooled to 7.5° and did not always produce them at 10°, but rots that had made a start at warmer temperatures continued to enlarge at 7.5° and even at 5°, but not at 2.5°. (Fig. 9.)

With Monilia needle inoculations, rots developed at practically 100 per cent of the punctures, and with Monilia dusting inoculations there was a very high percentage of infection at 10° C. and warmer and a gradual increase with time in the number of rots at 5° and 2.5°. (Fig. 5.) With Rhizopus, the infection from needle inoculations was not universal even at 25° and 30°, and at all lower temperatures it was very much poorer than with the Monilia dusting inoculations. (Figs. 5 and 8.) At 10° Rhizopus gave an average of only 22 per cent of infection 10 days after needle inoculation.

The infection from the Rhizopus dusting inoculations on punctured peaches was still poorer, never averaging more than 26 per cent even at the most favorable temperatures and being entirely lacking at 10° and colder. (Fig. 8.)

When once established, the Rhizopus rots enlarged at practically the same rate, regardless of the method of inoculation.

With Rhizopus, as already reported for Monilia, apparently sound peaches as well as the punctured ones were included in the dusting experiments. Rots occasionally developed on these dusted peaches, but not much more frequently than on the peaches that were not dusted. Apparently, germinating Rhizopus spores seldom if ever penetrate the sound skin of market-ripe peaches, and it is the opinion of the writers that the unbroken skin of the peach furnishes a complete protection against Rhizopus, except in cases where the sound fruit is in close contact with that which is already decayed.

DELAYS AT CONSTANT TEMPERATURES

In addition to the experiments in which the inoculated fruit was placed immediately at the temperature at which it was to be held, other tests were made in which it was delayed at a higher temperature before being placed at a lower one. The results are shown in Figures 10 to 17, inclusive.

APPLICATION OF EQUATED TEMPERATURE VALUES

So far as possible the results of the delays were interpreted in the light of the temperature studies previously reported and the actual growth compared with hypothetical growth curves developed from the temperature values of Figures 2 and 4.

As an illustration of the method of developing the hypothetical curves, the line c_1 of Figure 10 may be taken. After inoculation the peaches were held at 20° C. for 12 hours before storage at 7.5°. According to the values of Figure 4, 12 hours at 20° would allow Monilia to accomplish about 61 per cent of the work necessary to the production of a 5-mm. rot, leaving 39 per cent to be carried out at 7.5°, and according to the 7.5° values of the same figure 30 hours

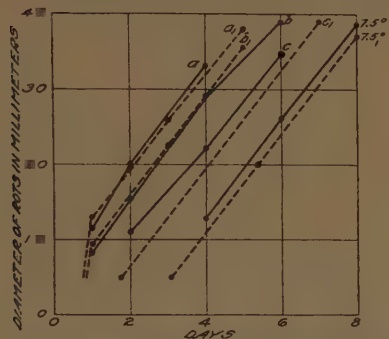

FIG. 10.—Effect of delay in cooling peaches that were needle inoculated with Monilia; the average of the results from 3 series of experiments, 1 each on Hiley, Belle, and Elberta. The solid lines give the actual results, the broken lines the estimated results based on the temperature values of Figures 2 and 4. Curves *a* and a_1, at 7.5° C. after 24 hours at 25°; *b* and b_1, at 7.5° after 24 hours at 20°; *c* and c_1, at 7.5° after 12 hours at 20°; also results at a constant temperature of 7.5°

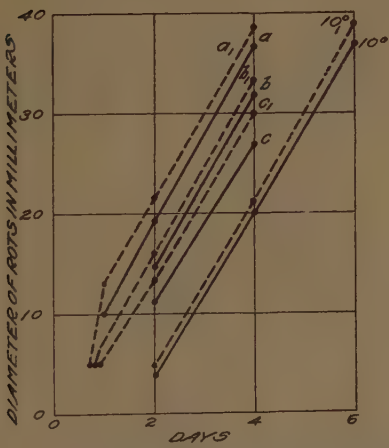

FIG. 11.—Effect of delay in cooling peaches that were needle inoculated with Monilia; the average of the results from 4 series of experiments, 1 each on Carman and Belle and 2 on Elberta. The solid lines give the actual results, the broken lines the estimated results based on the temperature values of Figures 2 and 4. Curves *a* and a_1, at 10° C. after 24 hours at 25°; *b* and b_1, at 10° after 22 hours at 20°; *c* and c_1, at 10° after 18 hours at 30°; also results at a constant temperature of 10°

would be required to complete the work at that temperature, making a total of 42 hours for the incubation period. After reaching the 5-mm. stage the rots would be expected to develop according to the growth values for 7.5°, as shown in Figure 2.

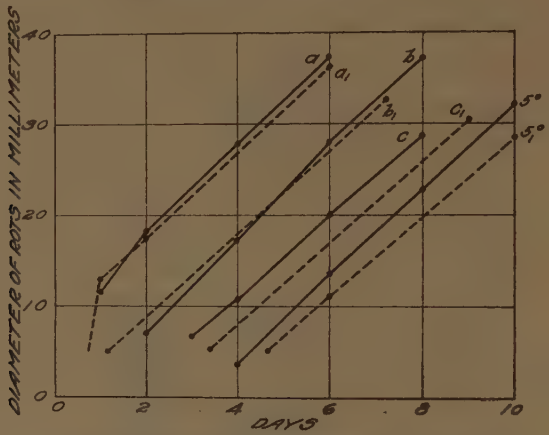

FIG. 12.—Effect of delay in cooling peaches that were needle inoculated with Monilia; the average of the results from 3 series of experiments, 1 on Hiley and 2 on Elberta. The solid lines give the actual results, the broken lines the estimated results based on the temperature values of Figures 2 and 4. Curves *a* and a_1, at 5° C. after 24 hours at 25°; *b* and b_1, at 5° after 18 hours at 30°; *c* and c_1, at 5° after 12 hours at 15°; also results at a constant temperature of 5°

A comparison of the hypothetical curves for the Monilia needle inoculations with the actual growth curves (figs. 10 to 12, inclusive) shows a fairly close agreement in most cases in both the incubation period and the rate of growth. In both the delayed and immediate-

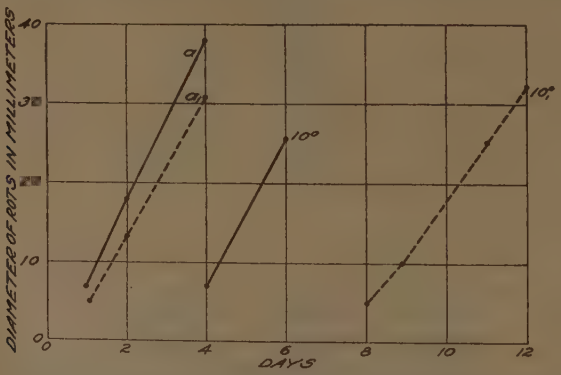

FIG. 13.—Effect of delay in cooling peaches that were needle inoculated with Rhizopus; the average of the results from 2 series of experiments, 1 each on Carman and Belle. The solid lines show the actual results, the broken lines the estimated results based on the temperature values of Figures 2 and 4. Curves *a* and a_1 at 10° C. after 18 hours at 25°. The peaches of the 10° curve were not cooled previous to inoculation

storage experiments at 10° C. the actual growth was behind the hypothetical; whereas at 7.5° and 5° the actual growth was usually ahead of the hypothetical, in three instances 8 to 15 hours ahead.

There would necessarily be a lag in temperature adjustment in moving the fruit from a higher to a lower temperature, and the

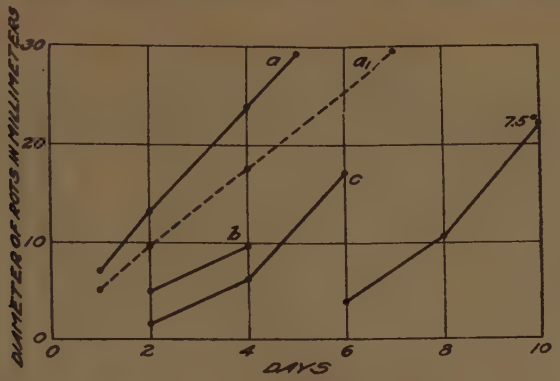

FIG. 14.—Effect of delay in cooling peaches that were needle inoculated with Rhizopus, the average of the results from three series of experiments on Belle peaches. The solid lines show the actual results, the broken line the estimated results based on the temperature values of Figures 2 and 4. Curves *a* and a_1, at 7.5° C. after 24 hours at 25°; *b*, at 5° after 18 hours at 25°; *c*, at 7.5° after 12 hours at 25°. As Rhizopus does not produce a rot when placed at once at 7.5° or 5°, the values of Figures 2 and 4 do not supply the data to estimate curves for *b* and *c*. The peaches of the 7.5° curve of Figure 14 were not previously cooled

fungus probably retains the stimulus of the higher temperature for a short time after removal to the lower, so it would be expected that

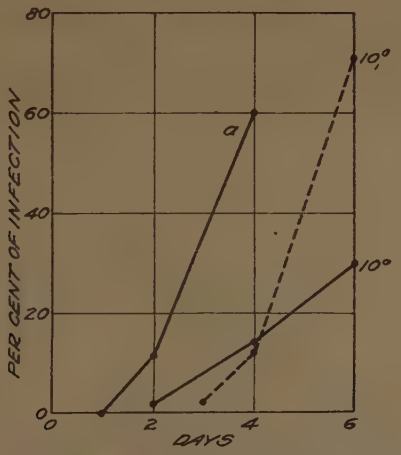

FIG. 15.—Effect of delay in cooling peaches to 10° C., as shown in the percentage of Monilia infection; the average of the results from 3 series of experiments, 1 each on Hiley, Belle, and Elberta. The peaches received 10 punctures each with No. 18 wire and were then dusted with Monilia spores. Curve *a* at 10° after 20 hours at 25°. The solid 10° line shows the results obtained in the present experiments; the broken line the average results of 16 tests as reported in Figure 5

the actual values might run somewhat ahead of the hypothetical, as developed by the methods described for Figures 2 and 4. The

differences between the hypothetical and the actual results, however, are little if any greater than the variation between the individual

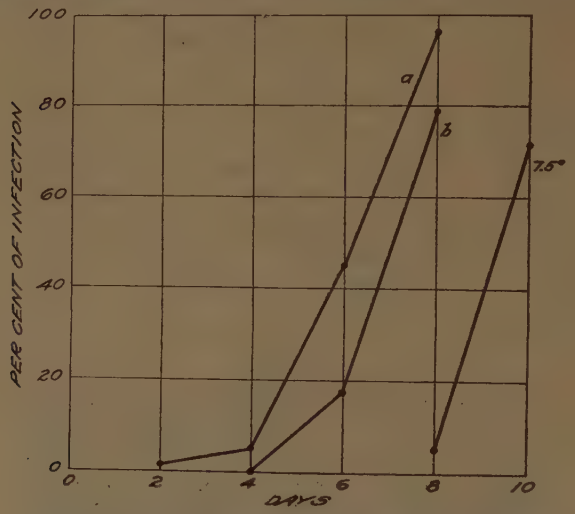

FIG. 16.—Effect of delay in cooling peaches, as shown in the percentage of Monilia infection, an experiment with Belle peaches. The peaches received 10 punctures each with No. 18 wire and were then dusted with Monilia spores. Curve *a*, at 7.5° C. after 24 hours at 20°; *b*, at 7.5° after 12 hours at 20°. The 7.5° graph shows results at that temperature held constant

experiments at constant temperatures as described in the legend for Figure 1.

In the case of the Rhizopus needle inoculations (figs. 13 and 14) the actual results were 15 to 30 hours ahead of the hypothetical.

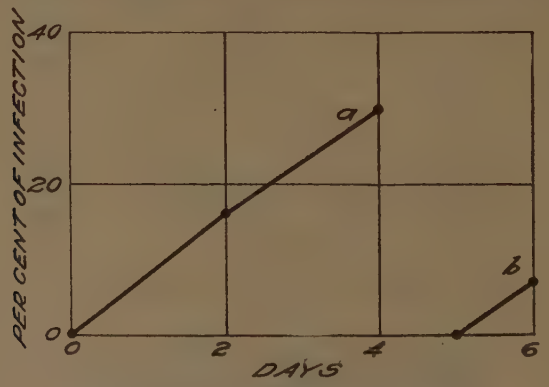

FIG. 17.—Effect of delay in cooling peaches, as shown in the percentage of Rhizopus infection, the average of the result from three series of experiments on Belle peaches. The peaches received 10 punctures with No. 18 wire and were then dusted with Rhizopus spores. Curve *a*, at 7.5° after 24 hours at 25°; *b*, at 7.5° after 12 hours at 25°. Warm inoculated peaches placed immediately at 7.5° did not develop rots

With the constant-temperature curves at 7.5° and 10° C., the contrast was much greater than this, but the peaches used in these experiments were not cooled before inoculating, whereas those upon which the

hypothetical values are based were cooled to approximately the storage temperature before inoculating. With the latter method no Rhizopus growth was obtained at 7.5°, and the growth at 10° was greatly delayed.

MONILIA NEEDLE INOCULATIONS

The effect of delay in cooling on Monilia needle inoculations is shown in Figures 10 to 12, inclusive. As compared with fruit stored immediately at 10° C., a delay of 24 hours at 25° put the rots about 44 hours ahead, a delay of 22 hours at 20° put them about 33 hours ahead, and a delay of 18 hours at 30° put them about 20 hours ahead.

As compared with immediate storage at 7.5° C., a delay of 24 hours at 25° gave the rots a lead of about 72 hours, a delay of 24 hours at 20° gave a lead of about 54 hours, and a delay of 12 hours at 20° gave a lead of about 34 hours.

As compared with immediate storage at 5° C., a delay of 24 hours at 25° gave the rots a lead of about 115 hours, a delay of 18 hours at 30° gave a lead of about 67 hours, and a delay of 12 hours at 15° gave a lead of about 33 hours.

MONILIA DUSTING INOCULATIONS

The effect of delay in cooling punctured peaches that were dusted with Monilia spores is shown in Figures 15 and 16. As compared with immediate storage at 10° C., a delay of 20 hours at 25° gave a lead of about 60 hours, as shown in the number of rots. As compared with immediate storage at 7.5° a delay of 24 hours at 20° gave a lead of about 88 hours, and a delay of 12 hours at 20° gave a lead of about 56 hours.

It will be noted that a given delay in cooling had much greater effect upon the dust inoculations than upon the needle inoculations as reported above, in fact about twice the effect. This is in agreement with the relative values reported in Figure 4.

RHIZOPUS INOCULATIONS

The effect of delay in cooling on Rhizopus needle inoculations is shown in Figures 13 and 14. Figure 17 shows the effect of delay in cooling dusting inoculations. A delay of 18 hours at 25° C. before storage at 10° accelerated needle inoculation rots about 76 hours. (Fig. 13.) A delay of 24 hours at 25° before storage at 7.5° caused an acceleration of about 150 hours, and a delay of 12 hours at 25° caused an acceleration of about 74 hours, as compared with warm peaches placed immediately at 7.5°. (Fig. 14.) Rhizopus rots did not develop at 7.5° when the peaches were cooled before inoculation. A delay of 18 hours at 25° before storage at 5° made it possible for the rots to appear at the 5° temperature. (Fig. 14.)

With peaches that were punctured and then dusted with Rhizopus spores, a delay of 24 hours at 25° C. before storing at 7.5° gave the rots a lead of five days over similar inoculations on peaches that were delayed but 12 hours at 25° before storing at 7.5°. (Fig. 17.)

A comparison of the results of Figure 17 with those of Figures 13 and 14 shows that delayed cooling had a very much greater effect upon Rhizopus dust inoculation than upon the needle inoculations. With both types of inoculation the effect of delayed cooling was much greater with Rhizopus than with Monilia.

DUPLICATION OF CAR-TEMPERATURE CONDITIONS

METHOD AND EQUIPMENT

The experiments previously reported were conducted in a series of six refrigerator boxes, each having a capacity of about 1 cubic yard. Each refrigerator box was supplied with a continuous and controlled stream of brine that was held at an approximately constant temperature. It was found that by setting the brine control so that the box

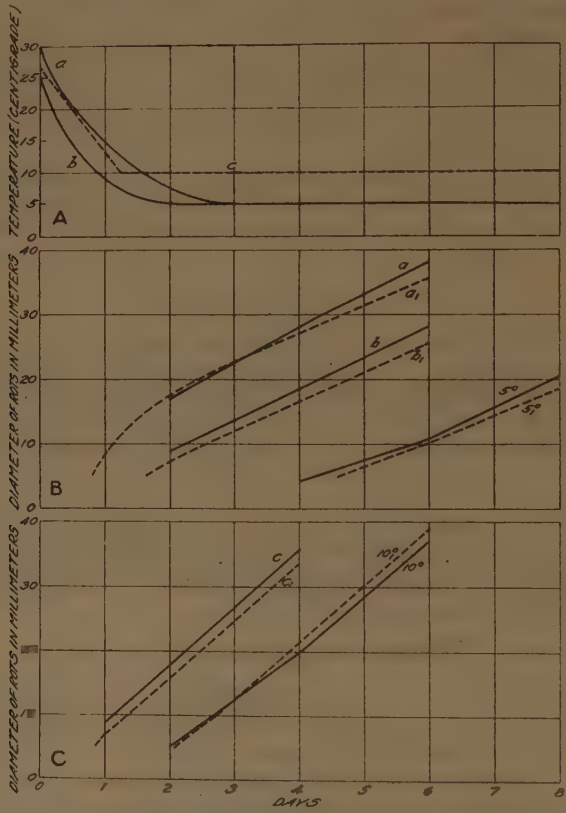

FIG. 18.—A, imitation car-temperature curves obtained in refrigerator boxes (see p. 522). B, growth curves for Monilia (needle inoculations) on Belle peaches at the temperatures shown in the curves of A and also at a constant temperature of 5° C. The solid lines give the actual results and the broken lines the estimated results based on the temperature values of Figures 2 and 4. Curves *a* and a_1, the rate of growth at the temperatures of curve A, *a*; *b* and b_1, at the temperatures of curve A, *b*. C, as B, but showing the growth at the temperatures of curve A, *c*, and also at a constant temperature of 10°

would be cooled to a temperature such as a car of fruit might have upon arrival at destination and then placing jars of hot water in the box a gradually falling temperature curve could be obtained similar to that of refrigerator cars. The initial temperature of the box was determined by the initial temperature of the water and the rate of cooling by the quantity of water used. The peaches were held at a distance from both the brine coils and the hot water, and the air of the box was kept in circulation by means of a slow-moving fan.

Complete temperature records were obtained by means of thermographs and standard thermometers placed beside the peaches. The temperature curves thus obtained are shown at A in Figures 18 and 19.

In addition to the car-temperature conditions, constant temperatures were maintained at the same time in other boxes of the series.

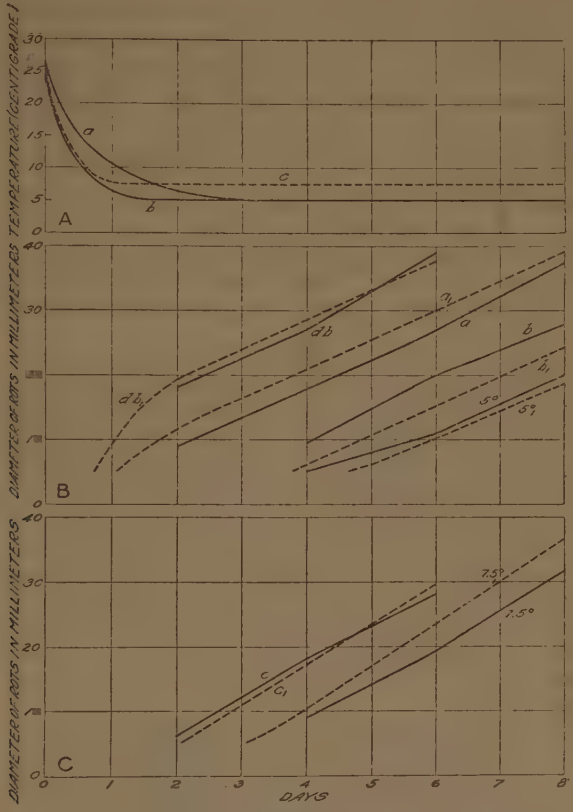

FIG. 19.—A, imitation car-temperature curves obtained in refrigerator boxes. B, growth curves for Monilia (needle inoculations) on Elberta peaches under the temperature conditions shown in curves A, *a*, and A, *b*, and also at a constant temperature of 5° C. The solid lines show the actual results and the broken lines the estimated results based on the temperature values of Figures 2 and 4. Curves *a* and a_1, rate of growth at the temperature of curve A, *a*; *b* and b_1, at the temperature of curve A, *b*; *db* and db_1, the rate of growth on peaches that were delayed at 26° for 24 hours before storing under the conditions shown in curve A, *b*. C, as B, but showing the growth of Monilia at the temperatures of curve A, *c*, and also at a constant temperature of 7.5°

APPLICATION OF EQUATED TEMPERATURE VALUES

The above conditions made it possible to hold part of a particular lot of inoculated peaches at a constant temperature while the others of the same lot were exposed to conditions similar to those that prevail in a refrigerator car. The results are shown in Figures 18, B and C, and 19, B and C. The solid lines show the actual growth and the broken lines the estimated growth based on the values of Figures 2 and 4.

The curves for the estimated growth were developed as described under "Delays at constant temperatures" (p. 516), except that instead of having two temperatures to consider there was often a different temperature for every hour. Curve a_1 of Figure 18, B, may be taken as an illustration. If the temperatures shown in the various hour periods of curve *a*, Figure 18, A, are converted into work units according to the values of Figure 4, it is found that 19 hours would be required for the Monilia rots to pass the incubation period and reach a diameter of 5 mm. They should then enlarge at a rate to be determined by converting the succeeding temperature values of curve *a*, Figure 18, A, into growth values according to the scale of Figure 2. The result is a gradually changing curve as shown in curve a_1 of Figure 18, B.

A comparison of the hypothetical Monilia curves with the actual growth curves shows practically as close agreement as was found with delays at constant temperatures. (Figs. 10 to 17, inclusive.) In five instances the actual growth was ahead of the hypothetical, in three instances behind it, and in three cases almost identical with it.

EFFECTS OF DELAYED COOLING

As compared with storing the Monilia-inoculated fruit immediately at 5° C., holding it at the temperature of curve *a*, Figure 18, A, gave the rots a lead of 130 hours; holding it at the temperature of curve *b*, Figure 18, A, or curve *a*, Figure 19, A, gave a lead of about 85 hours; holding it at the temperature of curve *b*, Figure 19, A, gave a lead of about 35 hours; and holding it at 26° for 24 hours and then at the temperature of curve *b*, Figure 19, A, gave a lead of about 135 hours. (Figs. 18, B, and 19, B.) As compared with storing inoculated fruit immediately at 7.5° C., holding it at the temperature of curve *c*, Figure 19, A, gave the rots a lead of about 38 hours. (Fig. 19, C.) As compared with storing it immediately at 10°, holding it at the temperature of curve *c*, Figure 18, A, gave the rots a lead of about 42 hours. (Fig. 18, C.)

The above accelerations in the time of the appearance of the rots resulting from the moderate delays shown in the curves of Figures 18, A, and 19, A, give evidence of the extreme importance of prompt loading and rapid cooling of harvested peaches.

PEACH ROTS IN TRANSIT

Experiments were also made in the standard refrigerator cars under commercial shipping conditions. The work was conducted in the years 1921 to 1926, inclusive, and included a record on 13 different refrigerator cars. The temperatures of Figure 20, A, are for cars shipped from Cornelia, Ga., to Chicago, Ill., but all other records are on shipments from Fort Valley, Ga., to New York City. The car-temperature curves are shown in Figures 20, A, to 30, A, inclusive.

METHODS AND EQUIPMENT

Except where otherwise stated, the cars were loaded four layers high with six-basket carriers, and the experimental peaches were placed in the middle of the stack, halfway between the bunker and the door. Half of the experimental lot was placed in the top layer and half in the bottom layer.

A thermograph was placed with each lot of peaches. It was fastened in the middle of the package, and peaches were packed around and in contact with it. It is believed that this arrangement gave the instrument practically the same temperature as the surface flesh of the fruit. The thermographs were tested before and after

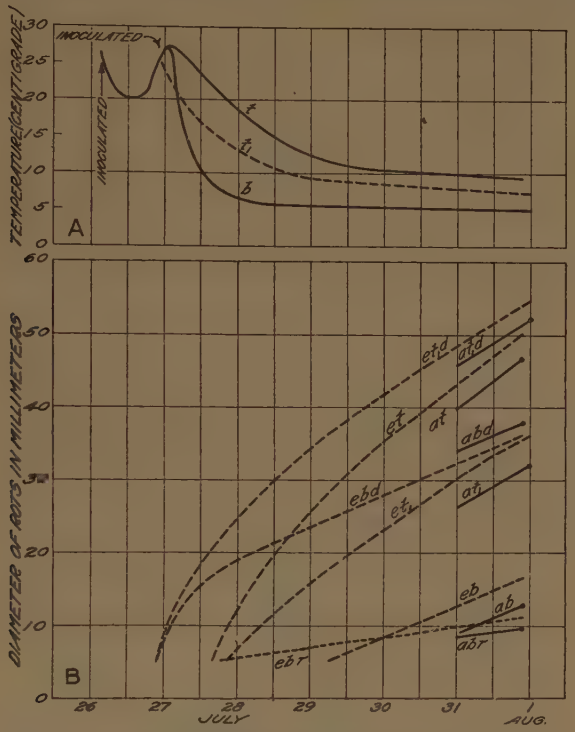

FIG. 20.—A, curves showing the temperature of peaches in two refrigerator cars that were loaded at approximately the same time, one with crates, the other with bushel baskets; also peach temperatures before loading. Curve *t*, fifth and top layer of crates in the fourth stack from the bunker; *b*, bottom layer of the same stack; t_1, third and top layer of baskets in the sixth stack from the bunker. B, development of rots (needle inoculations) on well-matured Elberta peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves give the estimated incubation and growth based on the values of Figures 2 and 4: Curves *et* and *at* give the results under the conditions of curve A, *t*, with Monilia inoculations 3 hours before loading; *eb* and *ab* under the conditions of curve A, *b*, with Monilia inoculations 3 hours before loading; *ebd* and *abd* under the conditions of curve A, *b*, with Monilia inoculations 22 hours before loading; et_1 and at_1 under the conditions of curve A, t_1, with Monilia inoculations at loading; et_1d and at_1d under the conditions of curve A, t_1 with Monilia inoculations 19 hours before loading; *ebr* and *abr* under the conditions of curve A, *b*, with Rhizopus inoculations 22 hours before loading

the shipment, and, as a further check on the instruments, the temperature of the peaches was always taken on arrival at destination. It is believed that with these various precautions a fairly accurate temperature record was obtained.

The inoculations were made as previously described (p. 507) except that 40 or more peaches were used under each condition.

APPLICATION OF EQUATED TEMPERATURE VALUES

With peaches in transit, a record of the actual development of the rots could be obtained only at the end of the shipment. But with the temperatures known it was possible to plot hypothetical growth curves according to the values of Figures 2 and 4, as described for the

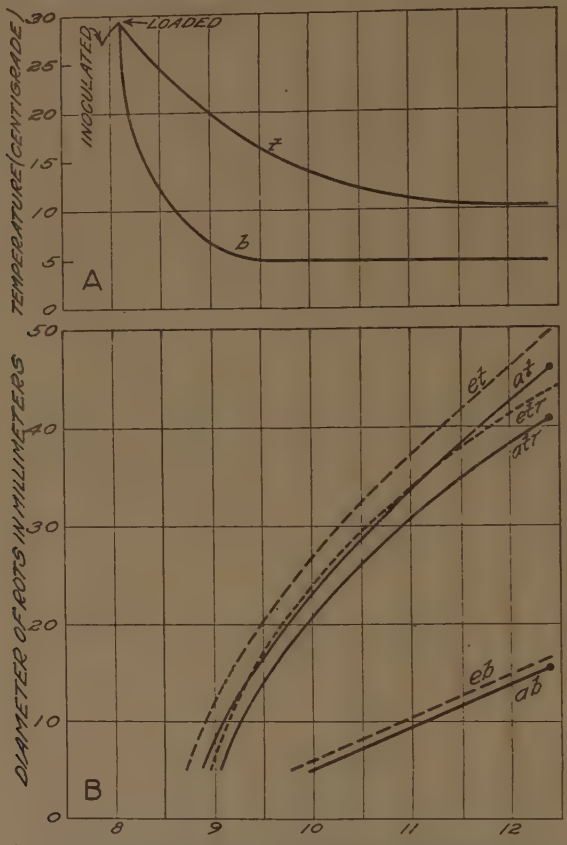

FIG. 21.—A, curves showing the temperature of peaches in a refrigerator car in transit and also the temperature before loading. Curve *t*, fourth and top layer of peach crates in the sixth stack from the bunker; *b*, bottom layer two stacks from the bunker. B, development of Monilia (needle inoculations) on well-matured Elberta peaches under the temperature conditions shown in A. The average size of the rots at the destination is shown by the position of the heavy dots at the right of the figure, *at* and *atr* for the top of the car and *ab* for the bottom. The solid lines connecting with these dots attempt to trace the growth curves backward by applying the growth values of Figure 2 to curves *t* and *b* of A. Curves *et*, *etr*, and *eb* give the estimated results under the conditions shown in A, based on the incubation values of Figure 4 and the growth values of Figure 2. Curves *etr* and *atr* refer to Rhizopus, the others to Monilia. All inoculations were made approximately four hours before loading

imitation car temperatures (p. 524), and it was also possible to trace the probable line of growth backward, with the size of the rots at the end of the shipment as a starting point. The hypothetical growth curves thus developed for the Monilia needle inoculations and a part of those for the Rhizopus needle inoculations are shown in Figures 20 to 30, inclusive.

Monilia Needle Inoculations

A study of the results of the Monilia needle inoculations shows that there were 11 instances in which the actual growth of the rots was ahead of the estimated growth and 29 instances in which it was behind. In 19 cases, however, there was not more than four hours' difference in the two. If these are excluded, only 2 instances remain in which the rots were ahead of the estimated growth and 19 instances in which they were 5 to 38 hours behind it. (See "Varietal resistance," p. 529.)

As shown in Figure 4 and emphasized in later paragraphs, needle-inoculation rots make a more rapid development than other types of Monilia infection. It is therefore evident from the above results that with the temperature of the fruit known, the incubation and growth can be plotted according to the values of Figures 2 and 4 with the expectation that there will be but few, if any, instances in which the actual growth will be ahead of that which has been estimated.

Monilia Dusting Inoculations

The results from the Monilia dusting inoculations are shown in Table 3. The rots average about one-third the size of the needle-inoculation rots exposed to the same conditions, which is approximately the ratio that holds in a comparison of Figures 1 and 6. The temperature values of Figures 4 and 6 do not form a basis for more than an approximate estimate on the results from dusting inoculations, but it can be said that in general the shipping results agree with the values shown in these figures. There are more instances in which the rots fall behind the expected results than exceed them.

Table 2.—*Development of Rhizopus rots on peaches in transit; needle inoculations*

Variety of peach	Temperatures as shown in—	Time of inoculation previous to loading (hours)	Condition upon arrival					
			Percentage of peaches affected		Average diameters of rots (millimeters)			
					Top of car		Bottom of car	
			Top of car	Bottom of car	Actual	Estimated[a]	Actual	Estimated[a]
Elberta	Fig. 21, A	4			41	44	0.2	0
Do	Fig. 20, A	22			Total.	Total.	9.5	11
Do	do	3			51	38	0	0
Yellow Hiley	Fig. 22, A	22			44.5	39	1.4	0
Do	do	6			18.4	21	0	0
Do	Fig. 28, A	5			.6	0	0	0
Elberta	Fig. 29, A	2			0	0	0	0
Hiley	Fig. 23, A	17	90	100	54.3	45	2.3	0–9
Do	do	2	30	0	6.3	28		
Do	Fig. 24, A	16–42	100	90	70.7	49	39.5	21
Do	do	6–32	100	70	42	37	15.0	5–10
Elberta	Fig. 25, A	14	50	20	29.2	32	3.1	0
Do	do	2	70	0	11.3	15		
Do	Fig. 26, A	16	80	50	15.4	46	3.8	11
Do	do	4	60	10	13.6	30	3.2	0

[a] Estimated on the basis of the values of Figures 2 and 4.

Rhizopus Inoculations

The results from the Rhizopus needle inoculations are shown in Table 2 and in Figures 20 to 25. In 6 instances the growth was

greater than would be expected from the values of Figures 2 and 4, in 4 instances it was less, and in 18 instances it was the same or prac-

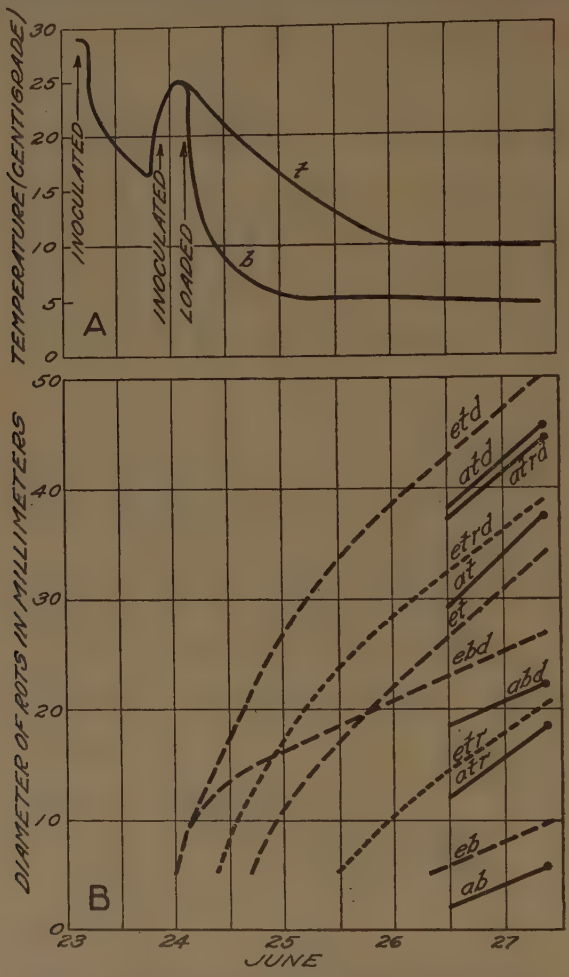

FIG. 22.—A, curves showing the temperature of peaches in a refrigerator car in transit and also the temperatures before loading. Curve *t*, fourth and top layer; *b*, bottom layer in the fourth stack of crates from the bunker. B, development of rots (needle inoculations) on Yellow Hiley peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actua size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves give the estimated incubation and growth based on the values of Figures 2 and 4: Curves *et* and *at* give the results under the conditions of, curve A, *t*, with Monilia inoculations 6 hours before loading; *etd* and *atd*, under the conditions of curve A, *t*, with Monilia inoculations 24 hours before loading; *eb* and *ab* under the conditions of curve A, *b*, with Monilia inoculations 6 hours before loading; *ebd* and *abd*, under the conditions of curve A, *b*, with Monilia inoculations 24 hours before loading; *etr* and *atr* under the conditions of, curve A, *t*, with Rhizopus inoculations 6 hours before loading; *etrd* and *atrd* under the conditions of curve A, *t*, with Rhizopus inoculations 24 hours before loading

tically the same; 10 of the 18 instances, however, were where both the actual and estimated values were zero or approximately zero.

As a whole, the results indicate that the Rhizopus values of Figures 2 to 4 represent about the average of what can be expected; but the rather wide variations from this average, in some instances, give further emphasis to the erratic nature of Rhizopus rots (p. 514).

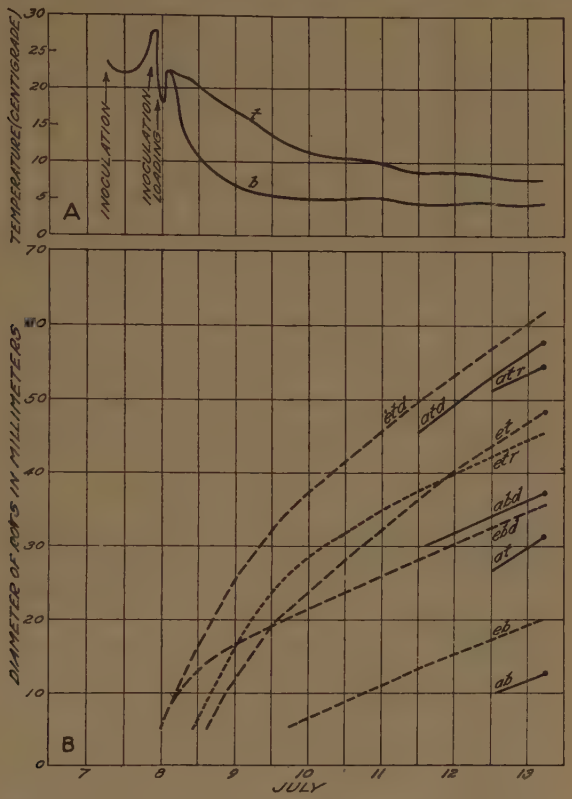

FIG. 23.—A, curves showing the temperature of peaches in a refrigerator car in transit and also the temperatures before loading. Curve *t*, fourth and top layer of crates in the fourth stack from the bunker; *b*, bottom layer in the same stack. B, development of rots (needle inoculations) on Hiley peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4: Curves *ei* and *at* give the results under the conditions of curve A, *t*, with Monilia inoculations 2 hours before loading; *etd* and *atd*, under the conditions of curve A, *t*, with Monilia inoculations 17 hours before loading; *eb* and *ab*, under the conditions of curve A, *b*, with Monilia inoculations 2 hours before loading; *ebd* and *abd*, under the conditions of curve A, *b*, with Monilia inoculations 17 hours before loading; *etr* and *atr*, under the conditions of curve A, *t*, with Rhizopus inoculations 17 hours before loading

VARIETAL RESISTANCE

A study of the tables and figures shows that with Monilia needle inoculations on Elberta peaches the actual growth was behind the estimated in 13 instances, ahead of it in none, and approximately the same in 9. With similar inoculations on Hiley peaches the actual growth was behind the estimated in 5 instances, ahead of it in 2, and

approximately the same in 11. The actual growth of Monilia on Elberta thus ran distinctly behind the estimated in 59 per cent of the tests and ahead in none. While on Hiley it ran definitely behind in only 28 per cent and ran ahead in 11 per cent.

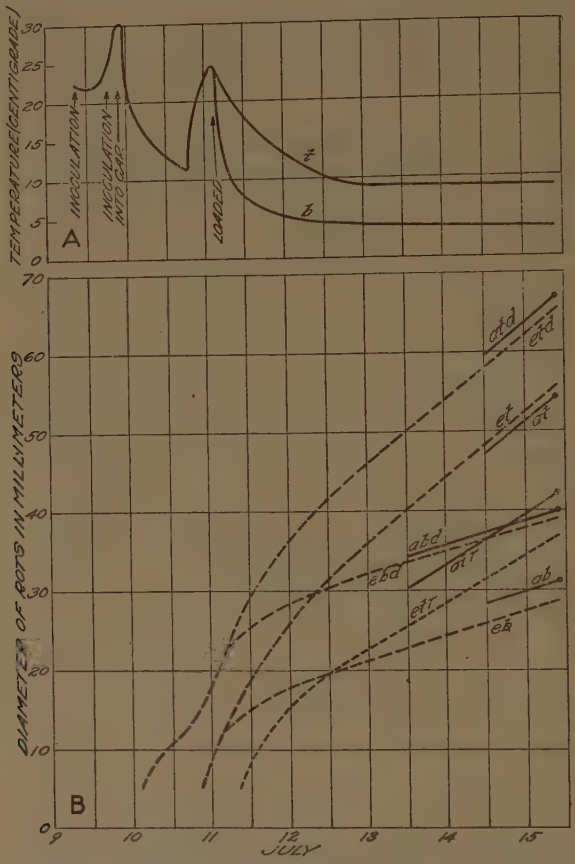

FIG. 24.—A, curves showing the temperature of peaches in a refrigerator car in transit and also the temperatures before loading. Curve *t*, fourth and top layer of crates in the fourth stack from the bunker; *b*, bottom layer in the same stack. B, development of rots (needle inoculations) on Hiley peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4: Curves *et* and *at* give the results under conditions of curve A, *t*, with Monilia inoculations 6 hours before cooling; *etd* and *atd*, under the conditions of curve A, *t*, with Monilia inoculations 16 hours before cooling; *eb* and *ab*, under the conditions of curve A, *b*, with Monilia inoculations 6 hours before cooling; *ebd* and *abd*, under the conditions of curve A, *b*, with Monilia inoculations 16 hours before cooling; *etr* and *atr*, under the conditions of curve A, *t*, with Rhizopus inoculations 6 hours before cooling

With Rhizopus needle inoculations on Elberta peaches the actual growth was behind the estimated in 3 instances, ahead of it in 1, and approximately the same in 11. With similar inoculations on Hiley peaches the actual growth was behind the estimated in 1 instance,

ahead in 5, and approximately the same in 7. On a percentage basis, the actual results were behind the estimated in 20 per cent of

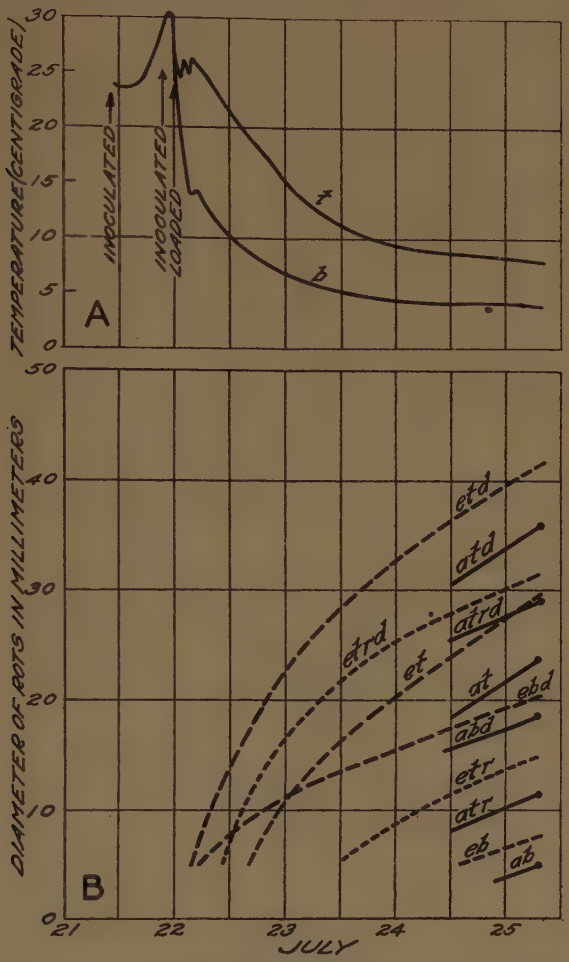

FIG. 25.—A, curves showing the temperature of peaches in a refrig erator car in transit and also the temperatures before loading. Curve *t*, fourth and top layer of crates in the fourth stack from the bunker; *b*, bottom layer of crates in the same stack. B, development of rots (needle inoculations) on Elberta peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4: Curves *et* and *at* give the results under conditions of curve A, *t*, with Monilia inoculations 2 hours before loading; *etd* and *atd*, under the conditions of curve A, *t*, with Monilia inoculations 14 hours before loading; *eb* and *ab*, under the conditions of curve A, *b*, with Monilia i noculations 2 hours before loading; *ebd* and *abd*, under the conditions of curve A, *b*, with Monilia inoculations 14 hours before loading; *etr* and *atr*, under the conditions of curve A, *t*, with Rhizopus inoculations 2 hours before loading; *etrd* and *atrd*, under the conditions of curve A, *t*, with Rhizopus inoculations 14 hours before loading

the tests with Elberta and in 8 per cent with Hiley; and they were ahead of the estimated in 7 per cent of the tests with Elberta and 38 per cent with Hiley.

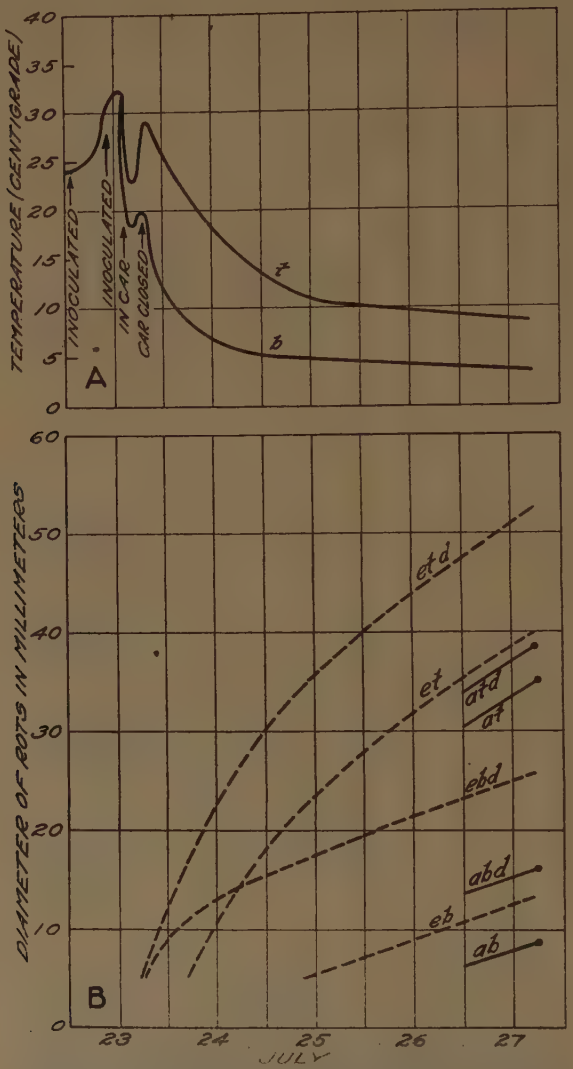

FIG. 26.—A, curves showing the temperature of peaches in a refrigerator car and also the temperatures before loading. Curve *t*, fourth and top layer of crates in the fourth stack from the bunker; *b*, bottom layer of crates in the same stack. B, development of Monilia (needle inoculations) on rather green Elberta peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4: Curves *et* and *at* give the results under the conditions of curve A, *t*, with inoculations 4 hours before loading; *etd* and *atd*, under the conditon of curve A, *t*, with inoculations 16 hours before loading; *eb* and *ab*, under the conditions of curve A, *b*, with inoculations 4 hours before loading; *ebd* and *abd*, under the conditions of curve A, *b*, with inoculations 16 hours before loading

The results indicate that Elberta peaches are considerably more resistant than Hiley to both Monilia and Rhizopus rots. This is in agreement with market reports and with general opinion. It should be noted, however, that the data for the shipment described in Figure 26 account for much of the resistance to rot shown by the Elberta variety and that the peaches of this shipment were rather green. It was noticed in a number of experiments that greenness seemed to introduce a greater factor of rot resistance with Elberta than with other varieties. In the present studies Elberta peaches in a market-ripe condition and with a broken skin have shown but little more resistance to rot than Hiley, Belle, or Carman. It is the opinion of the writers that the greater freedom from rot found in shipments of well-matured Elberta peaches is largely due to a greater resistance to punctures and bruises.

TYPES OF INOCULATION

Several different types of inoculation with Monilia were tested. The results from the needle inoculations are shown in Figures 20 to 30, inclusive, and the results from other methods in Table 3.

TABLE 3.—*Effect of different types of Monilia inoculation on peaches shipped under different temperature conditions*

HILEY PEACHES SHIPPED UNDER THE TEMPERATURE CONDITIONS SHOWN IN FIGURE 23

Treatment		Condition of fruit upon arrival					
		Percentage of peaches affected		Average diameters of rots (millimeters)		Average number of rots per peach	
Nature	Time before loading (hours)	Top of car	Bottom of car	Top of car	Bottom of car	Top of car	Bottom of car
No inoculation		4.8	2.2	22.6	25	0.05	0.02
Rubbed (not smeared) with rotten peaches carrying but few spores	17	100	95.3	Total.	68		
Do	2	100	26.7	45.6	12.4		
Dusted with spores (no punctures)	17	87.5	13.9	51.2	32.3		
Do	2	37.8	10.7	17.0	18.2		
Dusted with spores after receiving 20 pin-point punctures to the peach	17	97.3	64.7	13.8	4.6	4.3	1.4
Do	2	84.2	9.1	3.1	2.3	2.3	.1
Wet peaches punctured and dusted as above	17	100	92.5	Total.	4.8	(a)	7.1
Do	2	100	38.5	17.3	1.7	3.8	.9

HILEY PEACHES SHIPPED UNDER THE TEMPERATURE CONDITIONS SHOWN IN FIGURE 24

No inoculation		7.1	2.8	22.8	14.9	0.08	0.03
Rubbed (not smeared) with rotten peaches carrying but few spores	6-32	80	52.9	37.8	29.7		
As above, but with peaches that had received 20 pin-point punctures to the peach	6-32	100	100	Total.	31.8		
Dusted with spores (no punctures)	16-42	30	29	23.8	19.8		
Do	6-32	32.4	2	24.8	58.0		
Dusted with spores after receiving 20 pin-point punctures to the peach	16-42	100	73.8	57.4	30.4	(a)	1.6
Do	6-32	97.4	76.9	10.8	7.6	3.5	2.4
Wet peaches punctured and dusted as above	16-42	100	100	Total.	58.8	(a)	(a)
Do	6-32	90	100	Total.	6.8	(a)	6.5

ELBERTA PEACHES SHIPPED UNDER THE TEMPERATURE CONDITIONS SHOWN IN FIGURE 25

No inoculation		1.1	0.9	28.8	22.5	0.01	0.01
Rubbed (not smeared) with rotten peaches carrying no evident spores	2	96.7	13.3	18.6	8.9	2.0	.1
Dusted with spores (no punctures)	20	59.3	0	12.3	0	.9	0
Do	2	37.5	0	7.4	0	.8	0
Dusted with spores after receiving 10 pin-point punctures to the peach	20	95.7	33.2	10.5	8.1	3.1	.6
Do	14	61.3	9.5	9.0	6.8	.9	.1
Do	2	38.6	3.0	6.3	6.2	.5	.03

TABLE 3.—*Effect of different types of Monilia inoculation on peaches shipped under different temperature conditions*—Continued

ELBERTA PEACHES SHIPPED UNDER THE TEMPERATURE CONDITIONS SHOWN IN FIGURE 26

Treatment		Condition of fruit upon arrival					
		Percentage of peaches affected		Average diameters of rots (millimeters)		Average of number of rots per peach	
Nature	Time before loading (hours)	Top of car	Bottom of car	Top of car	Bottom of car	Top of car	Bottom of car
No inoculation		2.6	0	21.5	0	0.03	0
Rubbed (not smeared) with rotten peaches carrying few if any spores	4	31.8	7.4			.6	.1
Dusted with spores (no punctures)	21	23.3	4.8	24.3	12.0	.3	.05
Do	15	6.9	3.5	8.6	11.8	.1	.05
Dusted with spores after receiving 10 pin-point punctures to the peach	26	71.9	46.4	17.5	10.2	1.4	1.0
Do	21	44.5	30.0	12.6	4.5	.7	.5
Do	15	85.2	10.5	18.4	10.6	2.6	.1
Do	4	16.7	0	13.2	0	.2	0

HILEY PEACHES SHIPPED UNDER THE TEMPERATURE CONDITIONS SHOWN IN FIGURE 30

CAR 1							
No inoculation		6	0	26.6	0	0.085	0
Dusted with spores after receiving 10 punctures each with No. 18 wire	2	100	7	15.3	16.0	5.9	.14
As above, but receiving 10 pin-point punctures each	2	95	12	17.8	8.7	4.2	.24
CAR 2							
No inoculation		8	1	32.0	22.5	.15	.04
Dusted with spores after receiving 10 punctures each with No. 18 wire	2	100	100	Total.*	11.0	Total.*	6.4
As above, but receiving 10 pin-point punctures each	2	100	78	Total.*	12.7	Total.*	2.3

* Rots confluent.

Needle inoculations gave practically 100 per cent infection in all cases. Of all the methods used they gave the largest rots at the end of the shipment thus indicating the shortest period of incubation.

Rubbing peaches with rotten fruit that carried few if any spores produced a high percentage of infection and a rapid rot, showing the serious results that may follow from allowing partly rotten peaches to come in contact with those that are intended for market.

Wetting the peaches before puncturing and dusting greatly increased both the percentage of infection and the size of the rots. This may have been partly due to a greater number of spores clinging to the wet fruit than to the dry, but the wetness probably also hastened germination and facilitated infection.

The rots on the peaches that were punctured and dusted without wetting averaged about one-third the size of the needle-inoculation rots, and as estimated by the growth values of Figure 2 were 2.5 to 3 days behind them in development.

The lead of the rots on peaches that were punctured before dusting over those that were dusted without intentional puncturing was in the number of the rots and not in their size. The same thing holds true in a comparison of the two types of dusted peaches with the

untreated checks. In fact the rots resulting from dry-dust inoculations a few hours before loading averaged much smaller than those on the untreated fruit. This difference was evidently due to the fact that most of the rots on the untreated peaches had made an earlier start than those on the dusted peaches.

The peaches that were punctured and dusted had an average of about four and five-tenths times as many rots as those which were dusted without puncturing and more than one hundred and sixty times as many as those which were untreated.

The results as a whole show that spores carried on the surface of the fruit may be a cause of serious loss in transit, especially if the peaches have been punctured or otherwise roughly handled.

Spores were rarely produced by the rots during the transit period, even when the needle-inoculation fruit was delayed in loading, and it is safe to state that they were never produced in time to develop rots before the arrival of the shipment at its destination. All of the rots developed, therefore, were produced by the spores or mycelium carried by the fruit at the time of loading.

SPRAYED AND UNSPRAYED FRUIT

The peaches used in all the previous experiments had been sprayed according to prevailing orchard schedules, but the writers were fortunate in being able to obtain comparable lots of sprayed and unsprayed fruit from the experimental plots of John W. Roberts and John C. Dunegan at Fort Valley, Ga. The peaches described as unsprayed had received no fungicidal treatment whereas the sprayed fruit had been given the full spray-schedule treatment. The peaches were picked and packed under commercial conditions, apparently sound peaches only being included in the pack. One to three crates of peaches were used under each shipping condition. The results are shown in Table 4.

TABLE 4.—*Percentage of sprayed and unsprayed peaches affected with Monilia rot in transit*

[All fruit was apparently sound at the time of packing]

Variety	Year	Temperature as shown in—	Percentage of peaches affected with Monilia rot at the time of unloading			
			Top		Bottom	
			Sprayed	Unsprayed	Sprayed	Unsprayed
Yellow Hiley	1922		13.3	32.8	5.9	13.1
Hiley	1921		10.0	13.5	1.6	2.8
Elberta	1921	Fig. 21, A	27.3	91.1	5.3	39.9
Yellow Hiley	1922	Fig. 22, A	4.6	26.4	2.2	12.5
Do	1923	Fig. 27, A	11.8	31.7	6.3	12.5
Do	1923	Fig. 28, A	1.7	21.4	.5	7.9
Elberta	1923	Fig. 29, A	1.3	3.7	0	0
Hiley	1924	Fig. 23, A	4.8	16.7	2.2	11.7
Do	1924	Fig. 24, A	7.1	37.3	2.8	25.2
Elberta	1924	Fig. 25, A	1.1	12.0	.9	9.1
Do	1924	Fig. 26, A	2.6	42.2	0	13.1
Average			7.8	29.9	2.5	13.4

The unsprayed peaches developed far more brown rot in transit than the sprayed ones, in many cases eight to ten times as much. The average for 11 cars showed 7.8 per cent of the sprayed fruit in the top of the cars affected with Monilia rot, as compared with 29.9 per cent of the unsprayed fruit; and 2.5 per cent of the sprayed fruit in the bottom of the car was similarly affected, as compared with 13.4 per cent of the unsprayed fruit. The results show that the value of orchard spraying does not end in the orchard, but follows the fruit to its final destination.

In the top of the car the unsprayed peaches had practically the same percentage of rot as sprayed peaches that had been dusted (not punctured) with Monilia spores a few hours before loading, but in the bottom of the car the unsprayed peaches had more than three times as many rots as the comparable lots of dusted peaches. (Tables 3 and 4.) This contrast between the top and the bottom of the cars might be explained on the hypothesis that at the time of loading the unsprayed peaches carried fewer spores but more incipient rots than sprayed peaches which were dusted with Monilia spores; the temperature of the bottom of the car causing a greater relative decrease in infection than in the development of rots that had already made a start.

The results of the various experiments emphasize the importance of having the peaches as free as possible from spores as well as infections at the time they are loaded for shipment.

DELAYS BEFORE LOADING

A study of the results from Monilia needle inoculations (figs. 20 to 27, inclusive) shows that with this type of infection every hour of delay before loading puts the rots in the top of the car more than three hours ahead and those in the bottom of the car more than five hours ahead.

A similar study of the Rhizopus needle inoculations (Table 2, interpreted by Figures 2 and 4) shows that every hour of delay before loading put the rots in the top of the car nearly five hours ahead. The delays also greatly increased the percentage of infection. A delay of 10 to 15 hours sometimes meant three to five times as many infections, and in other cases it meant the difference between no infection and 20 to 100 per cent of infection.

The effect of delay upon the Monilia dusting inoculations was also significant, but not easy to summarize. A delay of a few hours before loading often meant two to three times as many rots at the end of the shipment, sometimes 10 to 12 times as many. Where there was little contrast in the number of rots, the effect of the delay was usually evident in their size, the rots on the delayed fruit often being several times as large as those on the fruit that was more promptly loaded.

COOLING OF THE CAR

A comparison of Figures 20 to 30, inclusive, shows considerable variation in the cooling of the different cars. Since the inoculations and the fruit in the different cars were not usually comparable, it is impossible to accurately interpret these differences in cooling in terms of actual rot development at the destination. A comparison can be made, however, on the basis of the values of Figures 2 and 4.

A study of the results reported in Figures 25 and 30 shows that the fruit of the two shipments had practically the same temperature

at the time of loading, but that at the end of 24 hours, the top of the car described in Figure 25 was down to 15° C. while the top of one of the cars described in Figure 30 had reached only 22.5°. According to the values of Figures 2 and 4 this difference in temperature meant that the rots in the top of one car were developing nearly

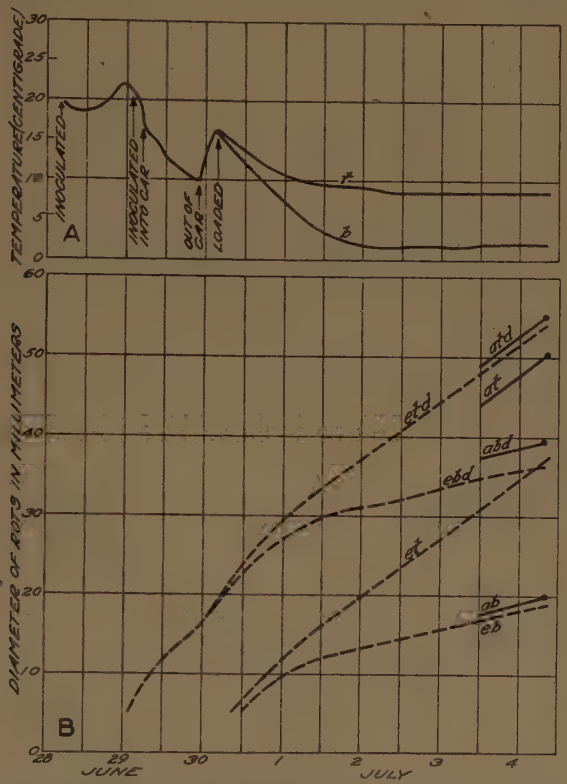

FIG. 27.—A, curves showing the temperature of peaches in a refrigerator car in transit and also the temperatures before loading. The experimental peaches were held inside the refrigerator car the night previous to final loading, and the temperature curves probably do not show the condition of the general load. Curve *t*, fourth and top layer in the fourth stack of crates from the bunker; *b*, bottom layer of the same stack. B, development of Monilia (needle inoculations) on Yellow Hiley peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4: Curves *et* and *at* give the results under the conditions of curve A, *t*, with inoculations 3 hours before cooling; *etd* and *atd*, under the conditions of curve A, *t*, with inoculations 24 hours before cooling; *eb* and *ab*, under the conditions of curve A, *b*, with inoculations 3 hours before cooling; *ebd* and *abd*, under the conditions of curve A, *b*, with inoculations 24 hours before cooling

twice as rapidly as those in the other. In the shipments described in Figures 24, 27, and 28, the temperature in the top of the car at the end of 24 hours was still lower than that of Figure 25, indicating a still greater check in the development of rots.

The most interesting contrasts in cooling, however, are to be found in a comparison of the top and the bottom of the same car.

CONTRAST BETWEEN THE TOP AND THE BOTTOM OF THE CAR[4]

If the temperature curves of Figures 20 to 26 and 28 to 30, inclusive, are interpreted in terms of the work values or time-temperature units

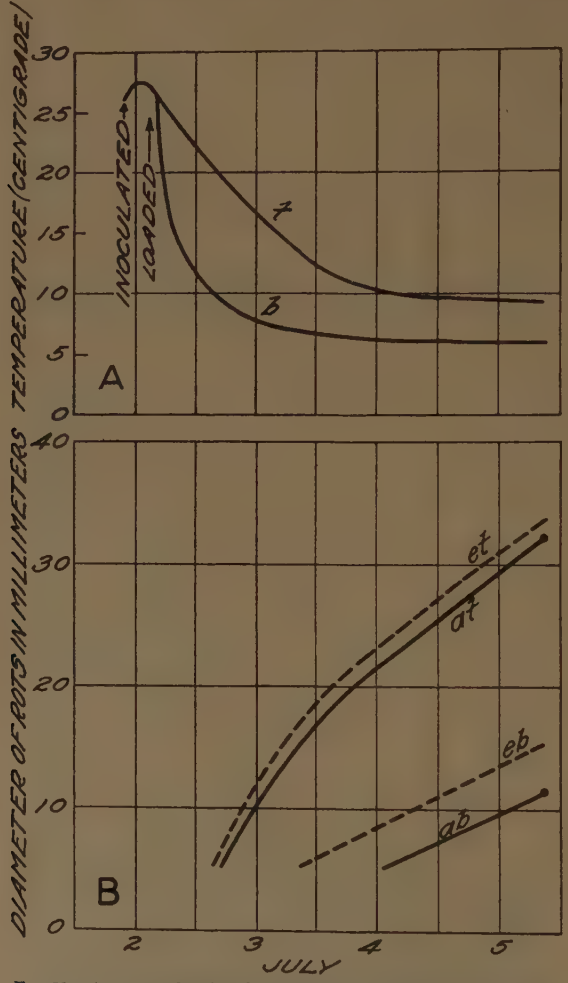

FIG. 28.—A, curves showing the temperature of peaches in a refrigerator car in transit and also the temperatures before loading. Curve *t*, fourth and top layer in the fourth stack of crates from the bunker; *b*, bottom layer of the same stack. B, development of Monilia (needle inoculations) on Yellow Hiley peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4. Curves *et* and *at* give the results under the conditions of curve *t*; *eb* and *ab* under the conditions of curve *b*. All inoculations were made five hours before loading

of Figure 4 with the development of a 5-mm. rot represented by 100, it is found that for Monilia needle inoculations the temperatures

[4] Reference is here made to cars loaded four layers high with six-basket carriers.

recorded for the bottom of the cars would have an average rating of 105, whereas those for the top of the cars would have an average rating of 266, or two and fifty-three hundredths times as high as that for the bottom of the cars. If instead of the needle-inoculation curve, the Monilia dusting and puncture curve is used, the ratings are about 53 for the bottom of the cars and 133 for the top of the cars. These ratings mean that in the bottom of the car Monilia spores pushed into

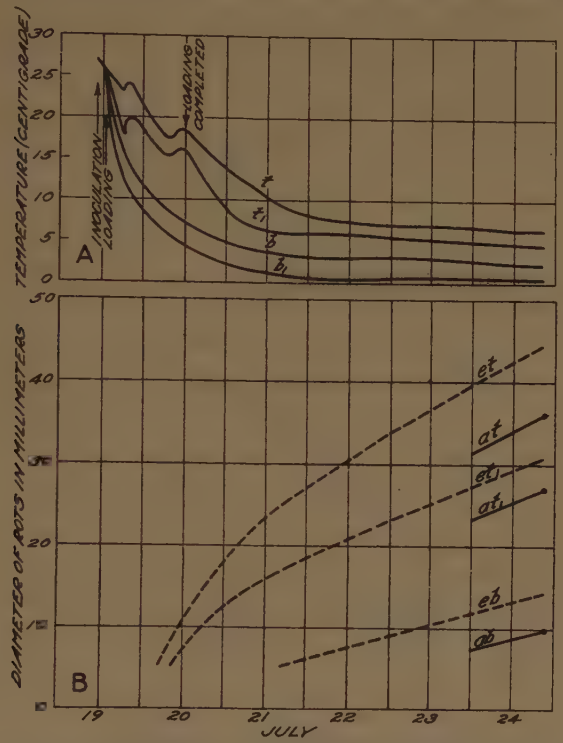

FIG. 29.—A, curves showing the temperature of peaches in a refrigerator car in transit. Curve *t*, fourth and top layer at the center of the car; *b*, bottom layer, center of the car; t_1, fourth and top layer next to the bunker; b_1, bottom layer next to the bunker. B, development of Monilia (needle inoculations) on Elberta peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination, and the lines connecting with these trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4. Curves *et* and *at* give the results under the conditions of curve A, *t*; et_1 and at_1 under the conditions of curve A, t_1; and *eb* and *ab* under the conditions of curve A, *b*. There was no growth under the conditions of curve A, b_1. All inoculations were made two hours before loading

the flesh of the peach in quantity would barely have time to produce a visible rot during the actual transit period, and with cooling such as is shown in Figures 22, 24, and 29 they would not have time to do so; and they also mean that spores lodged on the skin of a peach, even at a puncture, could rarely, if ever, produce a rot during such transit periods as are described in Figures 20 to 30, inclusive. In contrast to this, the ratings for the top of the car would give two and

six-tenths times as many work units as are required for Monilia needle inoculations to produce visible rots and one and one-third times as many as the average required for the production of rots by dusting spores on punctured peaches.

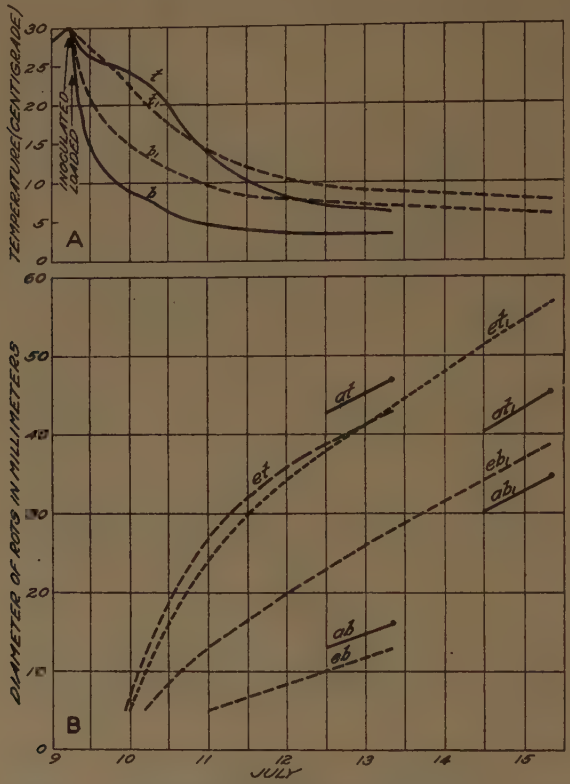

FIG. 30.—A, curves showing the temperatures of peaches in two refrigerator cars in transit and also the temperatures at loading. Curve *t*, fourth and top layer of crates in the fifth stack from the bunker; *b*, bottom layer of crates in the same stack of the same car; t_1, third and top layer of baskets two stacks from the door of the second car; b_1, bottom layer of baskets of the second car in front of the door; t_1, like previous test lots, was in the center of the car crosswise, but b_1 was in the outside row. B, development of Monilia (needle inoculations) on Hiley peaches under the temperature conditions shown in A. The position of the heavy dots at the right of the figure shows the actual size of the rots at the destination and the lines connecting with these dots trace the growth movement backward according to the values of Figure 2. The broken-line curves show the estimated incubation and growth based on the values of Figures 2 and 4. All inoculations were made one hour before loading: Curves *et* and *at* give the results under the conditions of curve A, *t*; *eb* and *ab*, under the conditions of curve A, *b*; et_1 and at_1, under the conditions of curve A, t_1; eb_1 and ab_1, under the conditions of curve A, b_1

With Rhizopus the contrasts between the top and the bottom of the car would be even greater than with Monilia, but not usually so evident in practical results, since in many cases the temperature of the top as well as the bottom of the car was too low for the production of rots during the transit period, even from needle inoculations.

The temperature contrasts between the top and the bottom of the car are composed of two factors, one the temperature level during the last days of the shipment and the other the length of time required to reach this level. The average temperature for the top of the car at the destination was about 4.5° C. higher than that for the bottom, but there was a period of 24 to 36 hours after the cars were closed when the top was 7° to 14° warmer than the bottom. According to the temperature values of Figure 4, nearly 60 per cent of the damage done by Monilia during the given transit periods in either the top or the bottom of the car was accomplished during the first 36 hours after the car was closed. Also, 60 per cent or more of the gain that the rots in the top of the car made over those in the bottom during the transit periods was accomplished during the first 36 hours, and with the shorter and more typical shipments the gain in the top of the car over the bottom was nearly twice as great during the first 36 hours as during the remainder of the period of shipment. The transit period could have been continued one to five days longer, or an average of about 41 hours longer, at the temperatures at which the shipments finished, before the damage resulting from the latter part of the shipment (about 103 hours) would have equaled that produced during the first 36 hours.

In the actual shipping tests, the inoculations were usually made several hours before the fruit was loaded, thus making the final results the combined effect of the car-temperature conditions and the delay in loading, and as previously pointed out (p. 536), the additive effect of the delay was sometimes more significant in the bottom of the car than in the top. In spite of this fact the actual results seem to fully support the differences outlined above.

A study of the growth curves in Figures 20 to 30, inclusive, shows that with the Monilia needle inoculations the actual work units accumulated in the top of the car averaged about 2.5 times as great as those for the bottom of the car, which is in agreement with the estimated values reported above. It should also be noted (based on growth curves continued backward) that, with inoculations made 1 to 6 hours before loading, the rots in the top of the car appeared 17 to 65 hours earlier than those in the bottom of the car and averaged about 42.5 hours earlier.

With Rhizopus needle inoculations made 1 to 6 hours before loading (Table 2), practically no rots started in the bottom of the car, whereas with the exception of the shipments of Figures 28 and 29 a good growth was made in the top of the car.

With Monilia dusting inoculations the contrast in the size of the rots in the top of the car and in the bottom was not so great as with the needle inoculations, but the contrast in the number of rots was especially significant. With the peaches that were punctured and dusted 1 to 6 hours before loading, there was an average of about fifty times as many rots in the top of the car as in the bottom at the destination of the shipment, and with peaches punctured and dusted 14 to 21 hours before loading there was an average of about 4 times as many rots in the top as in the bottom.

Peaches dusted with Monilia spores without puncturing developed about twenty times as many rots in the top of the car as in the bottom.

The regular commercial pack of fruit (Tables 3 and 4) averaged about four times as many rots in the top of the car as in the bottom.

The greater difference between the top and the bottom of the car in the case of peaches punctured and dusted 1 to 6 hours before loading than with those similarly treated 14 to 21 hours before loading would naturally be expected, owing to the fact that the delay gave the rots a chance to start before loading, and they were then able to continue to develop at the bottom as well as at the top of the car. The greater contrast with the dusted peaches than with the commercial pack probably has a similar explanation and is to be attributed to the fact that with the dusted peaches any infections already established are greatly outnumbered by the potential infections, whose development is determined by the temperatures of the transit period.

In commercial shipments the writers have frequently observed that while there are many more rots in the top of the car than in the bottom, there may be no corresponding contrast in the size of the rots. This is apparently due to the fact that the rots in the bottom of the car are confined largely to those that have made some start before loading, whereas many of those in the top of the car have developed during the transit period.

The various differences reported above are between the top and bottom carriers midway between the bunker and the door and do not show the extreme contrasts of the car as found between the bottom layers at the bunker and the top layers at the door. They are sufficient, however, to show the extreme variations in rot production that are often found in the same car.

SUMMARY

A study has been made of the relation of temperature, spraying, and type of infection to the transportation rots of peaches, and an attempt is made to equate the different temperature and infection values.

On the basis of temperature values developed and with the temperature conditions known, it has been found possible to picture the approximate course of development of the rots.

Monilia and Rhizopus rots increased in diameter at an approximately uniform rate in the different stages of development, the diameter of the rots thus becoming a fairly accurate basis for temperature comparisons. For the purposes of the present studies neither the area, nor the volume of the rot, nor the weight of the rotten tissue could be used as a basis for temperature equivalents.

With both Monilia and Rhizopus, low temperatures had a relatively greater inhibiting action upon development during the incubation period than during the later growth. With both incubation and growth a 5° C. change in temperature had a greater effect at the lower temperatures than at the higher ones (experiments ranging from 0° to 30°).

With inoculations made by dusting spores over punctured peaches, the incubation period for Monilia was about twice as long as with needle inoculations, and with spores dusted over apparently sound peaches the incubation period was still further prolonged. A similar contrast was found with Rhizopus, except that the fungus was apparently unable to penetrate the sound skin of market-ripe peaches.

The rots from Monilia dust inoculations continued to appear over a long period of time, whereas those from needle inoculations started off practically together. With Rhizopus there was considerable spread of the infection period in the case of both needle and dust inoculations.

When once established, the Monilia and Rhizopus rots that had resulted from dust inoculations enlarged as rapidly as those from needle inoculations.

Peaches that were punctured and then dusted with Monilia spores developed about four and five-tenths times as many rots as those that were dusted without puncturing and one hundred and sixty times as many as untreated peaches.

Apparently sound unsprayed peaches developed about four times as many rots in transit as similar sprayed peaches.

With dust inoculations and with fruit that had not been inoculated the contrast between the top and the bottom of the car and between delayed and immediate cooling was in the number of rots rather than in their average size. This was apparently due to a delay and spread in the infection period resulting from the lower temperatures and the more rapid cooling.

In the production of Monilia rots the temperatures of the top of the car had about two and five-tenth times the value of those in the bottom of the car, and about 60 per cent of this contrast and 60 per cent of the growth value in both the top and the bottom of the car were developed during the first 36 hours after the car was closed.

Monilia needle-inoculation rots appeared 17 to 65 hours earlier in the top of the car than in the bottom and averaged about 42.5 hours earlier. Peaches that were punctured and then dusted with Monilia spores 1 to 6 hours before loading, developed about fifty times as many rots in the top as in the bottom of the car, and peaches similarly treated 14 to 21 hours before loading developed about four times as many rots in the top as in the bottom of the car.

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